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A Review of Thermostat Energy Efficiency and Pricing

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Prepared for
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Executive Summary

The purpose of this study was to evaluate the energy efficiency and pricing of thermostats used for residential and commercial applications. There are numerous purchasing factors, market restraints, and market drivers that affect the ultimate selection of a thermostat. Examples of these factors include: product quality, product reliability, on-time delivery, customer service, technical support, ease of use, and environmental concerns. This study focused on the following two factors: energy efficiency and pricing.

The thermostat models selected for this study were limited to the following four technologies that are commonly used for residential and commercial applications:

1) Electromechanical with mercury switches,

2) Electromechanical without mercury switches,

3) Electronic nonprogrammable, and

4) Electronic programmable.

As a thermostat turns heating/cooling equipment on and off, the room temperature varies above and below the desired temperature. The range of the room temperature variations is referred to as temperature swing. When there is a large room temperature variation, there is a higher tendency for the thermostat user to adjust the thermostat setting upwards. This increase in the thermostat setting results in greater energy consumption. However, if the room temperature variation is too tightly controlled, there is excessive cycling of the heating/cooling equipment that may lead to reduced equipment longevity and equipment energy efficiency.

The temperature swing specification required by the U.S. EPA to achieve an Energy Star rating for electronic programmable thermostats is 4 degrees F or less. However, temperature swing data is not universally available from the various thermostat manufacturers. Consequently, this study used the combination of temperature differential and additional thermostat control functions to assess the energy efficiency performance of thermostats. Thermostat models that offer both a differential of 4 degrees F or less and have additional thermostat control functions are believed to have a reasonable likelihood of maintaining a temperature swing of less than 4 degrees F if properly installed and calibrated. For the purposes of this report, thermostat models with these characteristics are considered energy efficient.

For each of the four thermostat technologies reviewed, numerous models were identified that are energy efficient and are commercially available from several manufacturers. In general, the price range for the electromechanical thermostats is less than the price range for electronic thermostats. However, there is overlap between the higher end of the electromechanical price range and the lower end of the electronic thermostat price range.

In conclusion, a thermostat purchaser that focuses solely on energy efficiency and ignores all other purchasing considerations could meet this requirement with any of the four thermostat technologies reviewed in this report. A thermostat purchaser that focuses only on energy efficiency and low pricing could meet these requirements by purchasing electromechanical thermostats with either mercury switches or without mercury switches.

1.0 Key Definitions

There are sometimes variations in the definitions of thermostat terminology. For the purposes of this report, the following thermostat terms will be used consistent with the definitions provided in this section.

Anticipator control: Anticipator control is used to turn off the heating equipment before the room temperature actually reaches the cut-out point.

Cut-in Point: The air temperature at the thermostat at which it initiates action of heating/cooling equipment.

Cut-out Point: The air temperature at the thermostat at which it terminates action of heating/cooling equipment.

Cycle rate: Cycle rate is the frequency that heating or cooling equipment is turned on during a certain period of time. Cycle rate is often given in units of cycles per hour (CPH).

Differential: Differential is defined as the difference between the cut-in and cut-out points as measured at the thermostat under specified operating conditions. For example, if the thermostat turns the heating equipment on at 70 degrees F and turns the heating equipment off at 74 degrees F, then the differential is 4 degrees F.

Multi-stage thermostat: Multi-stage thermostats control multiple stages of auxiliary equipment for heating or cooling in response to varying levels of heating and cooling demand.

Programmable thermostat: A thermostat with the capability of automatically adjusting temperature set point to pre-selected settings at pre-selected times.

Setback: The automatic alteration of the thermostat control point(s) by means other than manually changing the temperature set point.

Set point: The desired temperature setting on an electromechanical or electronic thermostat.

Single-stage thermostat: Thermostats that activate the total heating or cooling capacity of the system. Examples include an oil furnace, gas furnace, or single speed air conditioning condenser.

System lag: The temperature drop in a heated room below the cut-in point of the thermostat. System lag reflects the temperature drop in a room that occurs between the time a furnace is turned on until the actual time when heat is delivered to the room. The converse is true for cooling systems.

System overshoot: The temperature rise in a heated room above the cut-out point of the thermostat. System overshoot reflects the increase in room temperature that occurs when the residual heat from a furnace reaches the room after the furnace has been shut off. The converse is true for cooling systems.

Temperature swing: The range between the highest and lowest room temperature attained by a thermostat. Temperature swing is calculated by the sum of differential, system lag, and system overshoot.

2.0 Scope

The scope of this review includes the following:

The thermostat models investigated were limited to low-voltage models used primarily for heating/cooling in residential and commercial applications. The thermostat models selected include single stage or multistage applications. This study was focused on thermostats utilizing on/off control capability. On/off control is the most basic kind of control where the heating and cooling equipment are turned on and off based upon thermostat outputs. The thermostats in this study also had additional control functions such as differential control, cycle rate control, and anticipator control.

The thermostat technologies selected for this study were limited to:

1) Electromechanical with mercury switches,

2) Electromechanical without mercury switches,

3) Electronic nonprogrammable, and

4) Electronic programmable.

This study did not include pneumatic, direct digital control, or other thermostat technologies that are not as commonly used for residential and light commercial applications.

This report describes thermostat technologies and provides detailed information for each thermostat model selected for energy efficiency features (i.e. differential, anticipator control, and cycle rate control), as well as for pricing information. The pricing information included in this report is for initial thermostat purchase price only, and does not include lifecycle costs such as cleanup costs for potential mercury spills from electromechanical thermostats with a mercury switch. This report does not provide detailed information for any other thermostat product features, functions, or purchasing factors.

3.0 Methods

Thermostat models were initially reviewed based on a literature search and by contacting thermostat manufacturers. Thermostat models were selected to be included in this study when the following three conditions were met:

- The thermostat had a differential of 4 degrees F or less.
- The thermostat provided additional temperature control functions such as differential control, cycle rate control, or anticipator control. These functions are described in further detail in subsequent sections.
- Adequate information was readily available from manufacturers and other sources for pricing as well as energy efficiency parameters such as differential and additional control functions.

The manufacturers of the selected thermostat models were contacted to determine the values and definition of their rated thermostat differential. Anticipator control, differential control, and/or cycle rate control information was also obtained for both heating and cooling modes. Thermostat pricing information was obtained from internet sources, retail stores, manufacturing list prices, and manufacturing retail prices.

This report was not reviewed in its entirety with the manufacturers listed in this report. These manufacturers should have the opportunity to review and comment on this report.

4.0 Thermostat Overview

4.1 Thermostat Introduction

Thermostats are devices that automatically measure and maintain a desired room temperature. Thermostats control room temperature by initiating and terminating the operation of the heating and cooling equipment when the room temperature falls outside a specified temperature range. The key components of a thermostat include the temperature sensor and the temperature switch. When the room temperature drops below a certain temperature, the thermostat sends an electrical signal to turn the heating equipment on. When the room temperature rises above a certain temperature, the thermostat sends an electrical signal to turn the heating equipment off. The converse is true for cooling applications.

Set point is the desired temperature setting on a thermostat. For the example provided in this section and shown in Figure 1, we will assume the thermostat user desires a room temperature of 70 degrees F, and has adjusted his/her thermostat set point to 70 degrees F. To achieve the temperature set point, the thermostat is designed with a cut-in point and cut-out point, or temperatures at which the thermostat sends a signal to the heating/cooling equipment. The cut-in point is the air temperature at the thermostat at which it initiates action of heating/cooling equipment. The cut-out point is the air temperature at the thermostat at which it terminates action of heating/cooling equipment.

The difference between the cut-in and cut-out temperature points is the differential. For example, if the thermostat turns the heating equipment on at 68 degrees F (cut-in point) and turns the heating equipment off at 72 degrees F (cut-out point), then the differential is 4 degrees F.

When the furnace is initially turned on, it will take a period of time for the heat to reach the room. And when the furnace is turned off, there is still some residual heat in the system. This can result in the room temperature varying slightly outside the cut-in and cut-out points of the thermostat. The range between the highest and lowest room temperature attained by a thermostat is referred to as temperature swing. The term “temperature swing” is sometimes used interchangeably with the term “temperature drift”. Temperature swing is calculated by adding the temperature differential, system lag, and system overshoot. For example, consider a thermostat with the following performance characteristics:

- Four degree differential (cut-in point of 68 degrees F and cut-out point of 72 degrees F)

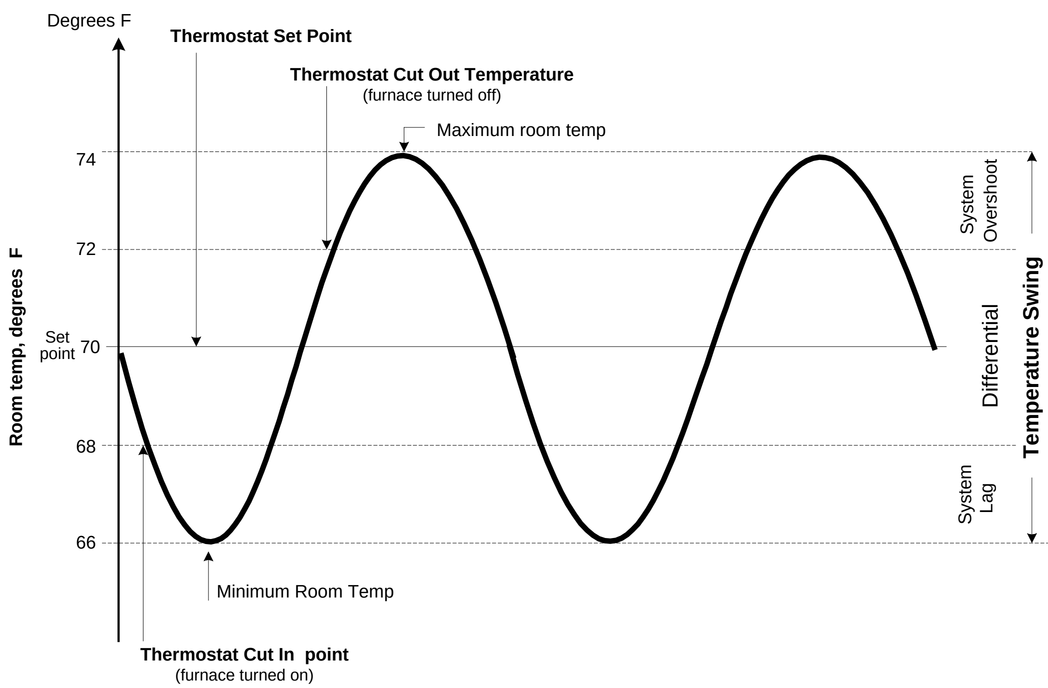
- System lag of two degrees F (down to 66 degrees F). This reflects the temperature drop in a room that occurs between the time a furnace is turned on until the actual time when heat is delivered to the room.

- System overshoot of two degrees F (up to 74 degrees F). This reflects the increase in room temperature that occurs when the residual heat from a furnace reaches the room after the furnace has been shut off.

Temperature Swing = 4 degrees F (differential) + 2 degrees F (system lag) + 2 degrees F (overshoot)

This thermostat would have a temperature swing of eight degrees F resulting in the room temperature ranging between 66 degrees F (coolest room temperature) and 74 degrees F (warmest room temperature). The room temperature variations for this example are illustrated in the figure below.

Figure 1: Temperature Control Example



Later sections of this report will review specific electromechanical and electronic thermostats and describe how they operate to maintain a desired room temperature. A brief overview of the thermostat market place is provided in Appendix A.

4.2 Temperature Swing Data Availability

Temperature swing data is typically not available from manufacturers. Of the manufacturers contacted for this report, only one manufacturer provided temperature swing data, and this data was available for only some of their thermostat models. Other manufacturers contacted either would not make their temperature swing data available to the public or did not collect temperature swing data for their thermostats. These manufacturers stated that this data is not shared with the public or collected because there are numerous variables that would affect the temperature swing performance in a testing environment versus during actual use. Examples of these variables include the following:

- Determining the proper location of a thermostat is critical to temperature swing performance. It is often recommended that the thermostat be mounted on an inside wall about five feet high. The thermostat should not be located near any unusual heating conditions (e.g. direct sunlight), cooling conditions (e.g. stairwell drafts), poor air circulation areas (e.g. corners), or excessive circulation areas (drafty areas).

- Building characteristics such as solar gain, insulation, and outdoor air infiltration.

- Heating and cooling equipment capacity versus the heating and cooling loads of the building.

- For electromechanical thermostats with mercury switches, the operation of the mercury switch may be affected if the switch is not level. Factors that may affect the level of the switch include: the accumulation of dust/dirt on the glass tube containing the mercury and proper leveling of the thermostat during installation and use.

- Major variations in outdoor air temperature.

- Proper installation, calibration, settings, and adjustments for anticipator, cycle rate, and differential control functions.

- Mismatch between thermostat and heating/cooling equipment (voltage, amperage, wiring, zones, and type of equipment).

- For electronic programmable thermostats, proper programming of the thermostat during installation and use.

For example, one manufacturer indicated that its thermostat was tested with a particular furnace system. However, the manufacturer stated that even using the same thermostat and furnace system, the actual results would vary depending on numerous site-specific factors that affect the heating and cooling load characteristics of each individual home.

The thermostat design and sophistication of its temperature control function affect how tightly room temperature can be maintained. Many thermostats are designed to provide enhanced temperature control and reduce the resultant temperature swing if properly adjusted and calibrated. These enhanced control functions include anticipator control, differential control, and cycle rate control. These control functions will be described in further detail in the next section of this report.

4.3 Thermostat Control

The on/off control mode is the most basic type of thermostat control system. For this most basic control type, the thermostat output is solely driven by the thermostat's cut-in and cut-out points. There are two states: fully on and fully off. The fully on state occurs when the temperature reaches the cut-in point and the fully off state occurs when the temperature reaches the cut-out point. In addition to on/off control, there are additional thermostat control functions that provide increased temperature control performance. Theses additional control functions include cycle rate control, anticipator control, and differential control.

4.3.1 Cycle Rate Control

Over the course of a day, a furnace (or air conditioner) might turn on and off numerous times. The cycle rate indicates how often heating or cooling equipment is turned on during a certain period of time. Cycle rate is typically expressed in cycles per hour (CPH).

The cycle rate is of interest because it determines how well controlled the room temperature is as well as the magnitude of the temperature swing. As the following table shows, the cycle rate affects the room temperature, occupant comfort, equipment energy efficiency, and equipment longevity. These four considerations are important in determining a reasonable cycle rate.

Table 1: Cycle Rate Advantages and Disadvantages

Cycle Rate	Advantages	Disadvantages
High – equipment turns on and off frequently	Room temperature is well controlled and there is a small temperature swing. The room is comfortable to the occupant because the temperature doesn't vary much.	Frequent starting and stopping of the heating and cooling equipment reduces equipment life and energy efficiency.
Low – equipment turns on and off relatively infrequently	Reduced starting and stopping of the heating and cooling equipment increases equipment life and energy efficiency.	Room temperature is not well controlled and there is a large temperature swing. The room may be uncomfortable for occupants and cause them to adjust thermostat.

Cycle rate control is generally not available in electromechanical thermostats. Cycle rate control is available in many electronic programmable thermostats and can be adjusted by the end-user during programming of the thermostat.

4.3.2 Anticipator Control

Another way of improving temperature control performance of a thermostat is to use anticipator control. This control function is often used to turn equipment on/off prior to reaching the actual cut-in and cut-out points of the thermostat, and therefore can reduce the magnitude of the temperature swing.

Consider the scenario in which a furnace has just heated a home to the thermostat cut-out point. When the combustion is stopped, there is still a considerable amount of heat remaining in the furnace. The fan is run to dissipate this residual heat in the furnace. This residual heat is often enough to drive the house temperature past the cut-out point. This rise in temperature above the cut-out point is referred to as system overshoot. The heat anticipator shuts off the heater before the air temperature in the vicinity of the thermostat actually reaches the cut-out point. The heat anticipator turns the heater off early to allow time for the residual heat to actually reach the thermostat and therefore reduce or eliminate system overshoot.

A common method of providing heat anticipator functionality in electromechanical thermostats is to use a loop of wire that functions as a resistor. As current passes through this wire, heat is generated that warms the bimetallic sensor causing it to unwind and activate the switch to shut the heater off. The length of the wire loop is often adjustable so that the heat anticipator setting can be field adjusted to a proper setting.

4.3.3 Differential Control

Some electronic programmable thermostats enable the end-user to directly adjust the temperature differential using the programming functionality. For example, one thermostat reviewed in this study had a preset temperature differential of 4 degrees F. The user is able to adjust the differential in 0.5 degree F increments.

4.4 Energy Efficiency

In general, the greater the temperature swing in a room, the more likely the user may adjust the thermostat set point higher during the heating season to maintain thermal comfort. The converse would be true for the cooling season. This adjustment of the set point is undesirable because it increases overall energy consumption. Ideally, the temperature swing would be small enough that occupants are consistently comfortable and are therefore less likely to make set point adjustments.

It is not possible to identify an exact temperature swing that will result in thermostat set point adjustment, because air temperature is only one of many factors that affect occupant thermal comfort. Other major factors affecting occupant thermal comfort include the insulation value of the occupant's clothing, activity level of the occupant, mean radiant temperature of surrounding surfaces, air speed, and humidity. In addition to occupant comfort, temperature swing is tied to energy efficiency and longevity of the heating/cooling equipment. While a smaller temperature swing may prevent the occupant from adjusting the thermostat, controlling temperature too tightly may result in excessive equipment cycling. This frequent starting and stopping of the heating and cooling equipment reduces equipment life and equipment energy efficiency.

There are numerous variables involved with occupant thermal comfort, end-user setback adjustment behavior, heating/cooling equipment cycling, and thermostat performance characteristics. Therefore, it is difficult to identify a universally acceptable temperature swing that optimizes occupant comfort, prevents excessive cycling of heating/cooling equipment, and achieves maximum energy efficiency for all circumstances.

A temperature swing of 4 degrees F is the specification required by the U.S. EPA to achieve an Energy Star rating for electronic programmable thermostats. This is generally considered as a tight enough control of room temperature to attain a reasonable balance among these variables and maintain energy efficiency.

There is a problem with using temperature swing as a performance criterion: most manufacturers do not typically provide this value for their thermostats. Temperature swing is comprised of the thermostat differential, system lag, and system overshoot. Of these, differential is the only well defined value available from manufacturers. Additional control functions (e.g. anticipator, cycle rate, and differential control) can provide enhanced temperature control and can reduce the resultant temperature swing if properly adjusted and calibrated. Thermostat models that offer both a differential of 4 degrees F or less and have additional control functions have a reasonable likelihood of maintaining a temperature swing of less than 4 degrees if properly installed and calibrated. For the purposes of this report, thermostat models that have a differential of 4 degrees F or less and have additional control functions are considered energy efficient.

5.0 Data for Selected Thermostat Models

Thermostat models were selected to be included in this section when the following three conditions were met:

- The thermostat had a differential of 4 degrees F or less.
- The thermostat provided additional temperature control functions such as differential control, cycle rate control, or anticipator control.
- Adequate information was readily available from manufacturers and other sources for pricing as well as energy efficiency parameters such as differential and additional control functions.

For the selected thermometer models, the upcoming sections will include tables with the following information:

Manufacturer: Name of the thermostat manufacturer.

Model: Thermostat model number and/or description.

Differential: The rated differential for the thermostat model in degrees F.

Additional Control Functions: This includes anticipator control, cycle rate control, or differential control information. If the control function is adjustable, the range of adjustments is provided where available.

Pricing: Pricing obtained for specific thermostat models. Multiple pricing sources are provided where available.

5.1 Electromechanical Thermostats with Mercury Switches

Electro-mechanical thermostats using mercury switches typically use a bimetal to sense temperature changes. The bimetal temperature sensor is a material consisting of two types of metals that change shape in response to temperature. The bimetal sensor is often comprised of brass and steel. The bimetal sensor is often coil shaped to activate a mercury switch based on angular rotation.

The mercury switch consists of a glass bulb filled with an inert gas and a small puddle of mercury that is free to move from one end of the bulb to the other. Wires are fastened to contacts inside the glass bulb. The glass bulb is fastened to the moveable end of the bimetal, so that it can rotate with the movement of the bimetal. When the bimetal rolls the glass bulb to a new position, the mercury rapidly makes or breaks the electric flow to control heating and/or cooling equipment.

The following table indicates the major manufacturers of electromechanical thermostats. A breakdown between manufacturers providing thermostats with and without mercury switches was not available.

Table 4: Manufacturers of Electromechanical Thermostats

Manufacturer	1999 Market share
Honeywell	66%
White-Rodgers	15%
Robertshaw	6%
Other	13%
Total	100%

Source: Frost & Sullivan, 2000

The following table provides differential, anticipator/cycle rate control, and pricing information for various models of electromechanical thermostats with mercury switches:

Table 5: Electromechanical Thermostats With Mercury Switches

Manufacturer	Model (Mechanical with Mercury Switch)	Differential (degrees F)	Additional Control Functions	Pricing
Honeywell	T87F Round	Heating: 4 Cooling: 4	*Anticipator Control* Heating: adjustable 0.1 to 1.2 Amps Cooling: 0 to 1.5 Amps	Grainger T87F2873 $24.39 Grainger T87F1859 $26.55 Grainger T87F3467 $34.15
Honeywell	CT51A	Heating: 4 Cooling: 4	*Anticipator Control* Heating: adjustable	Amazon $27.99
Lux	T10-1143	Heating: 3 Cooling: 3	*Anticipator Control* Heating: adjustable 0.15 to 1.2 Amps Cooling: fixed	Home Depot BB101143SA-004 $17.97
White-Rodgers	Single stage Low-Voltage 1E3x series	Heating: 1 Cooling: 1.5	*Anticipator Control* Heating: adjustable 0.15 to 1.0 Amps Cooling: fixed	Grainger 1E30-910 $26.25 Grainger 1E30-913 $26.75
White-Rodgers	Single stage Low-Voltage 1F3x series	Heating: 1 Cooling: 1.5	*Anticipator Control* Heating: adjustable 0.15 to 1.0 Amps Cooling: fixed	Grainger 01F35-910 $26.40

Summary

This section includes three manufacturers of electromechanical thermostats with mercury switches. Honeywell and White-Rodgers accounted for 81% of the total electromechanical thermostat market in 1999. The market share for Lux thermostats was not readily available.

The five thermostat models in this section each have a rated differential of 4 degrees F or less, and offer further temperature control by providing anticipator control functionality.

The price range for the five thermostat models in this section is $17.97 to $34.15.

5.2 Electromechanical Thermostats without Mercury Switches

Electromechanical thermostats without mercury switches often use a bimetal to sense temperature changes. The bimetal sensor is often U-shaped to activate a mechanical snap switch that makes or breaks the electric flow to control heating and/or cooling equipment. Electromechanical thermostats can also utilize magnets to open and close contacts enclosed in a glass bulb. Electromechanical thermostats with mercury switches and without mercury switches are often similar in specifications other than the switching mechanism. Appendix B provides an example of the similarities in specifications between electromechanical thermostats with and without mercury switches.

The following table provides differential, anticipator/cycle rate control, and pricing information for various models of electromechanical thermostats without mercury switches:

Table 6: Electromechanical Thermostats Without Mercury Switches

Manufacturer	Model (Mechanical without Mercury Switch)	Differential (degrees F)	Additional Control Functions	Pricing
Columbus Electric	RSU420GBCAXS	Heating: 2 Cooling: 2	*Anticipator Control* Heating: millivolt to 1.0 Amp Cooling: fixed	Grainger $18.12
Honeywell	CT 40	Heating: 4	*Anticipator Control* Heating: adjustable	True Value $19.99
Honeywell	T810 D	Heating: 4 Cooling: 4	*Anticipator Control* Heating: adjustable	Grainger T810D1003 $15.21 Honeywell T810D1003 $29.95
Robertshaw (Invensys)	500 Series	Heating: 1.5 Cooling: 1.5	*Anticipator Control* Heating: adjustable 0.3 to 1.2 Amps Cooling: fixed	Robertshaw List $24.22 - $38.10

Manufacturer	Model (Mechanical without Mercury Switch)	Differential (degrees F)	Additional Control Functions	Pricing
Robertshaw (Invensys)	9200 Series	Heating: 2 Cooling: 2	*Anticipator Control* Heating: adjustable 0.2 to 1.6 Amps Cooling: fixed	Robertshaw List $23.20 - $38.84
White-Rodgers	Single stage Low-Voltage 1C3x and 1D3x series	Heating: 1 Cooling: 1.5	*Anticipator Control* Heating: adjustable 0.15 to 1.0 Amps Cooling: fixed	Grainger 01D36-316 $26.30 Grainger 1C30-302 $25.45

Summary

This section includes four manufacturers of electromechanical thermostats without mercury switches. Honeywell, White-Rodgers, and Robertshaw accounted for 87% of the total electromechanical thermostat market in 1999. The market share for Lux thermostats was not readily available.

The six thermostat models in this section each have a rated differential of 4 degrees F or less, and offer further temperature control by providing anticipator control functionality.

The price range for the six thermostat models in this section is $15.21 to $38.84. However, the high end of this range is for Robertshaw thermostat list pricing that is typically higher than retail pricing.

5.3 Electronic Nonprogrammable Thermostats

Electronic nonprogrammable thermostats often use thermistors or other integrated circuit sensors to sense temperature changes. Thermistor operation is based on the fact that the electrical resistance of a material changes as its temperature changes. Thermistors rely on the resistance change in a ceramic semiconductor, with the resistance dropping non-linearly with a temperature rise. Thermistors provide a low cost solution to temperature measurement because they tend to have large signal outputs and their small size permits fast response to temperature changes.

Electronic nonprogrammable thermostats are similar to electro-mechanical thermostats in that they are set manually to a single temperature set point. The electronic nonprogrammable thermostat often provides an LED display for enhanced readability.

The following table indicates the major manufacturers of electronic nonprogrammable thermostats.

Table 7: Manufacturers of Electronic Nonprogrammable Thermostats

Manufacturer	1999 Market share
Honeywell	42%
Carrier Corp. (Totaline)	13%
Johnson Controls	11%
White-Rodgers	10%
Other	24%
Total	100%

Source: Frost & Sullivan, 2000

The following table provides differential, anticipator/cycle rate control, and pricing information for various models of electronic nonprogrammable thermostats:

Table 8: Electronic Nonprogrammable Thermostats

Manufacturer	Model (Electronic Nonprogammable)	Differential (degrees F)	Additional Control Functions	Pricing
Honeywell	T8400C	Heating: 1 Cooling: 1	*Cycle Rate Control* Heating: adjustable 1, 3, 4, 5, 6, 9, or 12 cycles per hour (CPH) Cooling: fixed at 3 CPH	Grainger T8400C1008 $48.95 Honeywell T8400C $54.95
Lux	DMH100	Heating: Default2 Adjustable to 1.5 Cooling: Default2 Adjustable to 1.5	*Anticipator Control* Automatically adjusts to the current draw of the controlled equipment	Home Depot BBDMH100-010 $21.97
Robertshaw (Invensys)	Deluxe 300-2xx	Heating: 1 Cooling: 1	*Anticipator Control* Built in software with anticipator algorithm	ICC Distributing 300-252 $18
Robertshaw (Invensys)	9500 Series Economy	Heating: 1 Cooling: 1	*Anticipator Control* Built in software with anticipator algorithm	Grainger 9500 $37.80 Grainger 9505 $35.70 Grainger 9520 $50.50

Manufacturer	Model (Electronic Nonprogammable)	Differential (degrees F)	Additional Control Functions	Pricing
Totaline (Carrier/ Venstar)	P474-0220	Heating: Default 2 Adjustable 1 – 6 Cooling: Default 2 Adjustable 1 – 6	*Cycle Rate Control* Default value of 6 CPH Adjustable 2 to 6 CPH	Thermostat Shop $76.75
White-Rodgers	1 F9X series Comfort-Set 90	Heating: 0.5 to 1.5 Cooling: 0.8 to 2.2	*Anticipator Control* Heating: adjustable Cooling: adjustable	Grainger 1F96-344 $76.00

Summary

This section includes five electronic nonprogammable thermostat manufacturers. Honeywell, Totaline, and White-Rodgers accounted for 65% of the electronic nonprogrammable thermostat market in 1999. The market share for Lux and Robertshaw thermostats was not readily available.

The six thermostat models in this section each have a rated differential of 4 degrees F or less, and offer further temperature control by providing anticipator or cycle rate control functionality.

The price range for the six thermostat models in this section is $18.00 to $76.75.

5.4 Electronic Programmable Thermostats

Electronic programmable thermostats often use thermistors or other integrated circuit devices to sense temperature changes. Like the thermostat technologies described earlier, electronic programmable thermostats can be set to maintain a single temperature set point. In addition, electronic programmable can be programmed by the user to automatically set back the temperature at predetermined times and days. The program schedule can be altered by the user as desired. The intent of this design is to offer additional energy savings by automatically reducing the demand for heating or cooling, for example at night or when the occupants are at work. This report does not include the additional energy savings possible by properly programming the setback function of electronic programmable thermostats versus using manual set point adjustments.

Electronic programmable thermostats often have an LED display for enhanced readability and to provide additional information to the user. Examples of this additional information include filter change reminders for the heating/cooling equipment and system run-time data that shows how long the system has been running.

The following table indicates the major manufacturers of electronic programmable thermostats.

Table 9: Manufacturers of Electronic Programmable Thermostats

Manufacturer	1999 Market share
Honeywell	47%
Carrier Corp. (Totaline)	15%
White-Rodgers	11%
Other	27%
Total	100%

Source: Frost & Sullivan, 2000

The following table provides differential, anticipator/cycle rate control, and pricing information for various models of electronic programmable thermostats:

Table 10: Electronic Programmable Thermostats

Manufacturer	Model (Electronic Programmable)	Differential (degrees F)	Additional Control Functions	Pricing
Honeywell	T8000C	Heating: 1 Cooling: 1	*Cycle Rate Control* Heating: adjustable 1, 3, 4, 5, 6, 9, or 12 cycles per hour (CPH) Cooling: fixed at 3 CPH	Grainger T8000C1002 $64.50 Grainger T800C1010 $62.40
Honeywell	CT2700	Heating: 1 Cooling: 1	*Cycle Rate Control* Factory set at 6 CPH adjustable to 1, 3, 9 CPH	Home Depot $29.00 Honeywell $37.95
Honeywell	T8600D Chronotherm IV Deluxe	Heating: 1 Cooling: 1	*Cycle Rate Control* Factory set at 6 CPH adjustable to 1, 3, 9 CPH	Grainger T8600D2028 $122.55 Home Depot CT8602C2009 $99.00
Honeywell	CT3200A1001	Heating: 1 Cooling: 1	*Cycle Rate Control* Heating: Adjustable	Home Depot $59.98 Honeywell $44.95

Manufacturer	Model (Electronic Programmable)	Differential (degrees F)	Additional Control Functions	Pricing
Lux	TX1500	Heating: Default: 4 Adjustable 2.5 to 6.5 Cooling: Default: 4 Adjustable 2.5 to 6.5	*Differential Control* Adjustable.	Home Depot BB1500-010L $39.99
Robertshaw (Invensys)	9600 Series	Heating: 1 Cooling: 1	*Anticipator Control* Built in software algorithm to adjust anticipation	Grainger 9600 $45.95 Grainger 9610 $58.30 Grainger 9620 $62.35
Totaline (Venstar)	P374-1100	Heating: Default 2 Adjustable 1 – 6 Cooling: Default 2 Adjustable 1 – 6	*Cycle Rate Control* Default value of 6 CPH adjustable 2 to 6 CPH	Thermostat Shop $151.45
Totaline (Venstar)	P474-1050	Heating: Default 2 Adjustable 1 – 6 Cooling: Default 2 Adjustable 1 – 6	*Cycle Rate Control* Default value of 6 CPH adjustable 2 to 6 CPH	Thermostat Shop $82.75
White-Rodgers	1F8X-51 Series	Heating: Diff. 0.5 to 1.5 Cooling: Not listed	*Anticipator Control* Adjustable	Grainger 1F82-51 $60.50
White-Rodgers	1 F9X series Comfort-Set 90	Heating: 0.5 to 1.5 Cooling: 0.8 to 2.2	*Anticipator Control* Heating: adjustable Cooling: adjustable	Grainger 1F90-371 $111.30 Grainger 1F97-371 $112.75

Summary

This section includes five electronic programmable thermostat manufacturers. Honeywell, Totaline, and White-Rodgers accounted for 72% of the electronic programmable thermostat market in 1999. The market share for Lux and Robertshaw thermostats was not readily available.

The ten thermostat models in this section each have a rated differential of 4 degrees F or less, and offer further temperature control by providing anticipator, differential, or cycle rate control functionality.

The price range for the ten thermostat models in this section is $29.00 to $151.45.

There are numerous other electronic programmable thermostats that have a 4 degree F or less temperature swing to meet the requirements of the U.S. EPA Energy Star program. Appendix C provides a listing of these Energy Star thermostats.

6.0 Conclusions

Thermostat models that offer both a differential of 4 degrees F or less and have additional control functions have a reasonable likelihood of maintaining a temperature swing of less than 4 degrees if properly installed and calibrated. For the purposes of this report, thermostat models that have a differential of 4 degrees F or less and have additional control functions are considered energy efficient.

The following table summarizes the results of this report:

Table 11: Summary of Report Results

Factor	Electromechanical with Mercury Switch	Electromechanical without Mercury Switch	Electronic Nonprogrammable	Electronic Programmable
Number of energy efficient models included	5	6	6	10
Number of manufacturers of energy efficient models included	3	4	5	5
Price range	$17.97 to 34.15	$15.21 to $38.84	$18.00 to $76.75	$29.00 to $151.45

For each of the four thermostat technologies reviewed, there are numerous models that are energy efficient and are commercially available from several manufacturers. These thermostats have temperature differential of 4 degrees F or less and have additional control functions. For each of the four thermostat technologies, at least two models were identified that have a differential of 2 degrees F or less to provide further temperature control and energy efficiency.

In general, the price range for the electromechanical thermostats is less than the price range for electronic thermostats. However, there is overlap between the higher end of the electromechanical price range and the lower end of the electronic thermostat price range. The prices included in this report are for initial thermostat purchase price only, and do not include lifecycle costs such as cleanup costs for potential mercury spills from electromechanical thermostats with a mercury switch.

In conclusion, a thermostat purchaser that focuses solely on energy efficiency and ignores all other purchasing considerations could meet this requirement with any of the four thermostat technologies reviewed in this report. A thermostat purchaser that focuses only on energy efficiency and low pricing could meet these requirements by purchasing electromechanical thermostats with either mercury switches or without mercury switches.

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Appendix A: Thermostat Market

A detailed and comprehensive study of the North American thermostat marketplace was undertaken by the company Frost & Sullivan. This report did not indicate whether the data for electromechanical thermostats included units with and without mercury switches. The following table summarizes the major findings for the electromechanical, electronic nonprogrammable, and electronic programmable thermostats.

Table 2: Market Data for Thermostats

Market Variable	Electromechanical	Electronic Nonprogrammable	Electronic Programmable
Forecast growth rate	-3.5%	+5.3%	+3.7%
Replacement Rate	10 – 15 years	10 – 15 years	10 – 15 years
Market Drivers	➢ Price sensitive ➢ Ease of use ➢ Learning curve for electronic thermostat ➢ Replacement market ➢ New building construction	➢ Energy conservation initiatives ➢ Reliability issues with old technology ➢ Environmental concerns	➢ Energy conservation initiatives ➢ New building construction ➢ Replacements
Market Restraints	➢ Energy conservation initiatives ➢ System integration requirements ➢ Demand for mercury-free products ➢ Oil price increases ➢ Shrinking price gap between technologies	➢ Price ➢ Contractors demand for electromechanical ➢ Learning curve	➢ Difficulty of use ➢ Price ➢ Contractors pushing electromechanical

Source: Frost & Sullivan, 2000

The results of this report indicate that the operational life of the three technologies (electromechanical, electronic nonprogrammable, and electronic programmable) are comparable. The results of this report further indicate that based on current market drivers and restraints, the demand for electromechanical thermostats is declining and the demand for electronic thermostats is increasing.

Appendix B: Electromechanical Thermostat Specification Comparison

Electromechanical thermostats with mercury switches and without mercury switches are often similar in specifications other than the switching mechanism. The following table illustrates an example of the similarities in specifications between electromechanical thermostats with and without mercury switches. These thermostats are manufactured by White-Rodgers.

Specifications	**Electromechanical Thermostat with Snap-Action Switch White-Rodgers Model 1C30-333**	**Electromechanical Thermostat with Mercury Cell Switch White Rodgers Model 1E30-343**
Typical Application	Heat Only	Heat Only
Color	Beige	Beige
Stages (Heat/Cool)	1	1
System Switch	None	None
Fan Switch	None	None
Contacts	***Snap-Action***	***Mercury Cell***
Anticipation Heat/Cool	Adjustable	Adjustable
Range	50 to 90 degrees F	50 to 90 degrees F
Shape	Vertical	Vertical
Terminals	4, R5, (Y6)	4, R5, (Y6)
Anticipation, Heating	Adjustable from 0.15 to 1.0 Amps	Adjustable from 0.15 to 1.0 Amps
Anticipation, Cooling	Fixed	Fixed
Differential, Heating	1 degree F	1 degree F
Differential, Cooling	1.5 degrees F	1.5 degrees F
Dimensions, Vertical	4 ½” H x 2 ¾” W x 1 ½” D	4 ½” H x 2 ¾” W x 1 ½” D
Electrical Rating	30 VAC maximum, NEC Class II	30 VAC maximum, NEC Class II
Parts and Accessories	F92-0563, F61-2068, and F61-2072	F92-0563, F61-2068, and F61-2072

Source: White-Rodgers, product technical specifications, http://www.white-rodgers.com

Appendix C: Energy Star Thermostats

ENERGY STAR® Labeled Programmable Thermostats
Qualifying Product List, As of March 31, 2003

Manufacturer Name (Trade Name)	Product Family Name	Model Series
Aprilaire	Electronic Thermostat	8365, 8366
Aprilaire	Programmable Thermostat	8554
Aprilaire	Communicating Thermostat	8300
Aube Technologies, Inc.	Aube	TH101, TH102, TH104, TH104-347, TH110-SP-P, TH110-DP-P, TH110-DP-P-COM, TH111-P-120, TH111-P-240, TH140-28-01, TH141-HC-28
Braeburn Systems LLC	Braeburn	5000, 5050, and 5200
California Economizer	Programmable Thermostats	DIGICOM
Carrier Corporation	Carrier	TSTATCCPRH01-B, TSTATCCPAC01-B, TSTATCCPHP01-B, TSTATCCP2S01-B, TSTATCCPDF01-B, TSTATCCPRF01, TSTATCCPS701, TSTATCCPF701, TSTATCCPB501, TSTATCCSAC01, TSTATCCSHP01
Carrier Corporation	ComfortChoice	CFTCHCCPUISA
Carrier Corporation (Bryant)	Bryant	TSTATBBPRH01-B, TSTATBBPAC01-B, TSTATBBPHP01-B, TSTATBBP2S01-B, TSTATBBPDF01-B, TSTATBBPRF01, TSTATBBPS701, TSTATBBPF701, TSTATBBPB501, TSTATBBSAC01, TSTATBBSHP01
Climate Technology Corp (Hunter Fan Company)	Auto Changer 7-Day Programmable	43503
Danfoss Randall	Danfoss	TP75, TP57A, TP75B, TP75AB
Danfoss Randall	Danfoss	HC8110-1, HC8220-1, HC8191-1, HC8221-1
Danfoss Randall	Danfoss	HP8210-1, HP8320-1, HP8221-1, HP8321-1
Danfoss Randall	Danfoss	HC75-1, HC75A-1
Home Automation	Hai Omnistat	RC-Series ending in -8, -9x, -10x, -11x, -12x
Honeywell	Chronotherm IV Single Stage	All models beginning with T8600D, T8601D, T8602D, T8635, T8665
Honeywell	Chronotherm IV Heat Pump	All models beginning with T8611G, T8611M
Honeywell	Chronotherm IV Multi Stage	All models beginning with T8624D
Honeywell	Perfect Climate Comfort CenterTM	All models beginning with PC8900
Honeywell	Energy Management System	T7512, T7516, T7518
Honeywell	Honeywell Single Stage Programmable Thermostat	All Models beginning with CT3600, CT3650, CT3500, CT3550, CT3595, CT3697, CT8602

Manufacturer Name	Product Family Name	Model Series
Honeywell	Honeywell Heat Pump Programmable Thermostat	CT3611
Honeywell	Honeywell	All models that begin with T8000
Honeywell	Honeywell	All models that begin with T8001
Honeywell	Honeywell	All models that begin with T8011
Honeywell	Honeywell	All models that begin with T8024
Honeywell	Honeywell	All models that begin with T8002
Honeywell	Honeywell	CT3451: All Series A1000, A1018
Hunter Fan Company	Auto Saver Programmable Thermostat	44550
Hunter Fan Company	Auto Saver Programmable Thermostat	44450
Hunter Fan Company	Auto Saver 459	44459
Lennox	Lennox	All models beginning with L21, L22, L23
Lennox	Programmable Thermostat	Signature STaT
Lennox	Programmable Thermostat	Multi-Programming
Lennox	Programmable Thermostat	7-Day Programmable
Lennox	Programmable Thermostat	Programmable
International Controls and Measurements Corp. (ICM)	Simple Comfort	SC 3000
International Controls and Measurements Corp. (ICM)	Simple Comfort	SC 3001
Invensys	Insight	9701i
Invensys	Insight	9715i
Invensys	Insight	9720i
Invensys	Robertshaw	300-224
Invensys	Robertshaw	300-225
Invensys	Robertshaw	300-226
Invensys	Robertshaw	300-227
Invensys	Robertshaw	300-229
Invensys	Robertshaw	300-230
Invensys	Robertshaw	9610, 9615, 9620, 9700, 9710, 9720
Lux Products	Lux	TX500, BB500, ATX500
Lux Products	Lux	TX1500, BB1500, ATX1500
Lux Products	Lux	TX9000, BB9000, ATX9000
Lux Products	Lux	HP2110, BBHP2110 (Models that have HP2110)
Lux Products	Lux	ELV1, BBELV1, AELV1
Lux Products	LuxPro	PSPH605
Lux Products	LuxPro	PSPH521
Lux Products	LuxPro	PSPLV510
Lux Products	LuxPro	PSP600
Lux Products	LuxPro Series	PSP511
NUHEAT Industries Ltd.	TH111	FTGF-1P
NUHEAT Industries Ltd.	TH111	FTGF-2P
NUHEAT Industries Ltd.	TH115	NTG5110
NUHEAT Industries Ltd.	TH115	NTG52200
PSG Limited	Lin-Stat Setback	TDLV-240HS-SB
PSG Limited	Cadet Setback	C3003
Research Products	PerfectTemp	SK3, SHP-1, SHC-7, SHP-2, SMS-1
Rite Temp	Programmable	781-733
Rite Temp	Programmable	783-137
Rite Temp	Touch Screen	784-788

Manufacturer Name	Product Family Name	Model Series
Rite Temp	Touch Screen	785-224
Rite Temp	Touch Screen	785-605
Smart Systems International	SmartSystem	SS1000 series PTAC Controllers
Smart Systems International	SmartSystem	SS5000 series Computerized Thermostats
SmartWay Solutions, Inc.	Talking Thermostat	VT1000
Surf Networks	Amerilon TS Series	All models beginning with "TS"
Telenetic Controls	Teletemp	2000, 2010
Totaline	Totaline Gold Series	P274-1100, P274-1200, P274-1300
Totaline	Totaline Signature Series	P374-1100, P374-1100FM, P374-1500, P374-1600
Totaline	Totaline Star Series	P474-1050, P474-1100RF
Trol-A-Temp	Chronotherm IV Zoning Thermostat	T8601D2027, T8602D2026
UPM	Programmable Thermostats	THM301M
White Rodgers	Comfort-Set 80	All programmable models beginning with 1F8
White Rodgers	Comfort-Set 90	All programmable models beginning with 1F9

Note: Carrier owns Carrier, Payne, Bryant, D & N. The BB, CC, DD, or PP in the model # refers to the company. The P refers to programmable. 2S= two speed, AC= A/C, DF = duel fuel, HP= heat pump.